

# INTEGRATED PEDESTRIAN SAFETY ASSESSMENT PROCEDURE

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Paper Number 13-0268

## ABSTRACT

Structural improvements at the vehicle front are state of the art in the field of pedestrian safety today and offer a basic passive protection. Meanwhile advanced safety systems have entered the market. Deployable systems, like the active bonnet or the windscreen airbag, further enhance the passive protection of passenger vehicles while systems of active safety such as autonomous emergency braking (AEB) are able to mitigate or even avoid an accident due to a reduction in collision speed. However, an integrated assessment of active and passive pedestrian safety is a current challenge. A procedure to assess and compare the safety potential as well as the effectiveness of active and passive safety measures on one scale was presented at the last ESV conference (paper 11-0057) and has been further enhanced since then. In addition, an existing external test protocol for advanced forward-looking pedestrian safety systems has been implemented into the assessment procedure, which enables a vehicle-model-specific evaluation of active safety systems for children and adults.

An important characteristic of the assessment procedure is its modular design, combining structural characteristics of a vehicle front with accident kinematics and accident research data. The procedure uses the results of the Euro NCAP pedestrian protection tests of the car to be assessed and adapts the HIC values to the real accident kinematics derived from numerical simulations. Kinematics parameters are the head impact velocity, impact angle and impact probability. The assessment procedure finally provides index values for children and adults, which indicate the risk for an AIS3+ head injury due to the primary impact depending on the collision speed.

A first update to the procedure, which is already prepared for the Euro NCAP-GRID, has been made

with respect to the pedestrian size distributions used to determine the impact probabilities for the particular wrap-around-distance zones of the vehicle front. Both distributions, i.e. for children and adults, are now based on current GIDAS data and establish a direct link to the actual accident situation. Further changes have been carried out regarding the weighting and adaptation of the Euro NCAP values, resulting in a new correlation between head impact velocity and HIC. At last the index calculation itself has been revised by the use of a more convenient injury risk curve.

For active pedestrian safety systems the reduction in collision speed achieved within the particular test scenarios specified in the external test protocol forms the main assessment criterion. A methodology has been developed, which implements those test results according to their relevance into the assessment procedure and enables the calculation of a corresponding index value. A case example describing an AEB system equipped with a warning function has been defined in order to demonstrate the methodology.

Index values are calculated for six real passenger car fronts, all representing different vehicle classes. Beside the basic vehicle, an active bonnet, a windscreen airbag and the generic AEB system are each assessed. The corresponding index values reveal, which pedestrian safety systems are most effective for the different vehicle classes as well as pedestrian groups.

## INTRODUCTION

Due to increasing requirements from European legislation and in particular on the part of consumer ratings advanced pedestrian protection measures have gained relevance in the past few years. Structural improvements at the vehicle front offer only a basic passive protection and often implicate limitations with regard to design. Meanwhile advanced safety systems have entered the market,

which offer additional safety features. Deployable systems, like the active bonnet or the windscreen airbag, further enhance the passive protection of passenger vehicles while systems of active safety, such as autonomous emergency braking (AEB), are able to mitigate or even avoid an accident due to a reduction in collision speed. However, an integrated assessment of active and passive pedestrian safety is a current challenge.

Within a joint research project of fka and the German Insurers Accident Research a procedure to assess and compare the safety potential of active and passive safety measures on one scale has been developed and presented at the last ESV conference [1]. Meanwhile some improvements have been made to the modular procedure, which will be illustrated within this paper. Since those changes solely affect individual modules, the procedure itself will only be summarised. For this reason it is recommendable to read [1] first.

With regard to active pedestrian safety systems the reduction in collision speed forms the main assessment criterion. In [1] the evaluation of active safety systems has been generally demonstrated by the help of a simplified accident analysis. Based on given system specifications of different generic systems general speed reductions have been derived and transferred into according index values. However, a vehicle-model-specific assessment of real active safety systems requires relevant test scenarios as well as uniform and reproducible boundary conditions. Therefore an external test protocol has been implemented into the assessment procedure. With the help of a methodology, an active safety index is calculated based on the decelerations achieved in the different scenarios.

Both the improvements made to the assessment procedure and the implementation of an existing external test protocol for advanced forward-looking pedestrian safety systems are described in the following.

## UPDATES TO ASSESSMENT PROCEDURE

The assessment procedure combines structural characteristics of the vehicle front with accident kinematics and accident research data. It uses the results of the Euro NCAP pedestrian protection tests of the car to be assessed and adapts them to the real accident kinematics derived from numerical simulations. Kinematics parameters are the head impact velocity, impact angle and impact probability. The assessment procedure finally provides index values for children and adults, which indicate the risk for an AIS3+ head injury due to the primary impact depending on the collision speed. The whole process is automated to

a large extend so that the user has not to know all the details behind it.

The procedure is divided into six modules. Within the first three modules all vehicle characteristics required for the assessment are determined (Table 1). If desired, a seventh module allows a qualitative assessment of secondary impact.

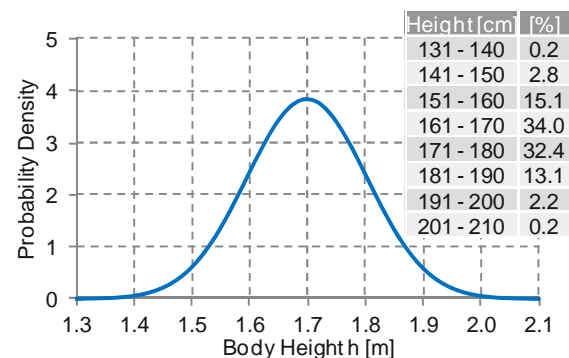
**Table 1.**  
**Modules of the assessment procedure**

|   |   |                         |
|---|---|-------------------------|
| 1 | Measurement and vehicle zoning                    | Vehicle characteristics |
| 2 | Simulation and accident kinematics                |                         |
| 3 | Structural properties and passive safety systems  |                         |
| 4 | Weighting and adaptation of structural properties | Assessment              |
| 5 | Index calculation                                 |                         |
| 6 | Assessment of active safety systems               |                         |

A first update to the procedure has been made with respect to the pedestrian size distributions used to determine the impact probabilities for the different zones of the vehicle front.

## Pedestrian size distributions

The correlation between wrap-around-distance (WAD) and body height derived from the simulations performed in module 2 is the first step towards WAD-zone-related impact probabilities. A second step combines this data with a pedestrian size distribution. Since the assessment is carried out for children and adults two separate size distributions have to be defined, which are now based on current GIDAS data to establish a direct link to the actual accident situation. Figure 1 shows the size distribution defined for adults while Figure 2 illustrates the corresponding WAD distribution resulting from the described procedure.



*Figure 1.* Pedestrian size distribution for adults (GIDAS, frontal accidents, n=685). [2]

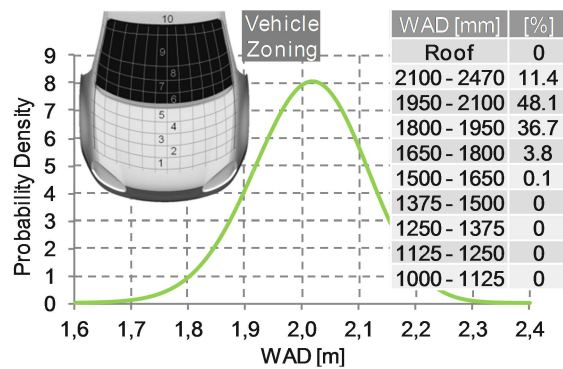


Figure 2. Relevance of WAD zones (adults, example vehicle).

Besides impact probabilities simulation-based impact velocities and angles are automatically assigned to every WAD zone as well. In a next step the structural properties of the vehicle front have to be determined for all fields of the WAD zones.

### Euro NCAP-GRID procedure

The structural properties are described by the Head Injury Criterion (HIC). These data is taken from the respective Euro NCAP spreadsheet of the car to be assessed. The recent introduction of the GRID procedure [3] facilitates the assignment of HIC values to the particular fields of the vehicle zoning. The tight grid of test points and the provided colour prediction for each point result in an improved mapping of the structural properties (Figure 3). However, this requires an adaptation of the vehicle zoning as well as the corresponding calculation of probabilities. The index values presented in this paper are unaffected by this since the related vehicles have not been tested with the GRID procedure.

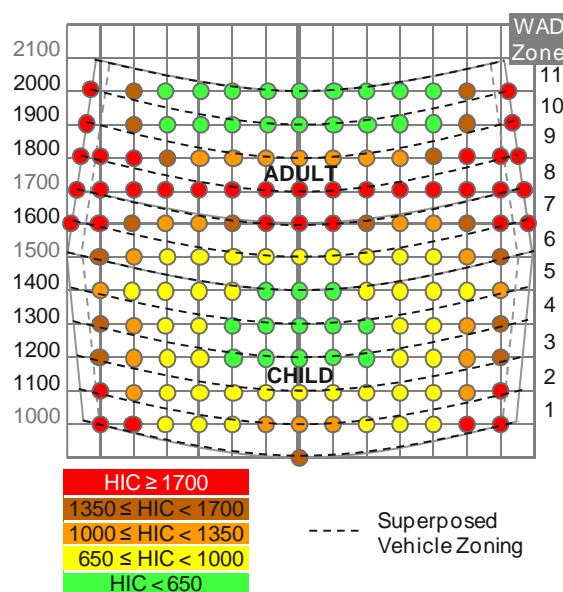


Figure 3. Vehicle zoning for Euro NCAP-GRID procedure (generic result).

The GRID procedure is based on the existing reference lines of the child and adult test zones. Hence, position and dimension of the head test zone remain unchanged. In order to utilise the advantages of the close grid all WAD zones are adapted to the prescribed distance between the particular test points, which is 100 mm. The total number of WAD zones is thereby, under consideration of the two zones outside the Euro NCAP test area, increased from ten to thirteen. The new vehicle zoning is illustrated in Figure 3. The assignment of the kinematics parameters can be carried out as before.

Since the dimension of the WAD zones in longitudinal direction corresponds to the distance between the grid points a clear assignment of HIC values is ensured. Solely in the case that two points are exactly positioned on two adjacent reference lines, which for example applies to the points on the central longitudinal line, a rule has to be defined. Here, each grid point is assigned to the preceding WAD zone. The foremost point, which lies on the first reference line (WAD 1000), however forms a special case since there is no preceding WAD zone. Hence, the average value of the two points lying on the reference lines of WAD zone 1 is assigned.

Longitudinal reference lines are not necessary since they arise from the constant grid. With regard to the calculation of the relevance factors (module 4) it should be noted that the number of grid points in lateral direction may vary, especially in the area of the A-pillars. Here, the GRID procedure provides additional points outside of the side test lines, which are represented by a dotted line in Figure 3. Those points lie on the intersections of the lateral grid lines and the side reference line (solid line).

### Weighting and adaptation of structural properties

Within the fourth module of the assessment procedure the structural properties are combined with the accident kinematics. For the weighting and adaption of the HIC values several factors are defined. Those factors are integrated into the calculation formula of the head index (module 5). Each factor represents one of the kinematics parameters evaluated in module 2.

The weighting of the particular vehicle fields with regard to the impact probabilities is carried out by relevance factors. Two relevance factors are defined, one for the lateral and one for the longitudinal direction. For the GRID procedure the relevance factor in lateral direction does no longer possess the same value for all WAD zones but is calculated by the number of grid points within one WAD zone. In case of the generic result in Figure 3

it amounts to 1/13 in the bonnet area and 1/15 in the windscreen area. Thus, the variable name changes to  $R_{ij,lateral}$ . The relevance factor in longitudinal direction ( $R_{i,WAD}$ ) remains unchanged and represents the impact probabilities of the particular WAD zones at a specific collision speed.

The Euro NCAP tests are performed with definite boundary conditions, i.e. constant values for impactor velocity and angle [3]. The velocity factor ( $V_{i,j}$ ) adapts the standardised Euro NCAP head impactor results to the maximal head impact velocities coming from the kinematics analysis. The definition of the velocity factor has been revised and adapted to the five colour scale of the GRID procedure. The velocity factor is based on analytical approaches and simulation results. Figure 4 illustrates the associated relationship between HIC value and impact velocity. The underlying family of curves is implemented into the index calculation. On the basis of the Euro NCAP result at the regarded test location it enables the automated determination of correspondent HIC values for both reduced and increased impact velocities without conducting further tests. With regard to impact velocities above 40 km/h it has to be assumed that the available deformation space at well tested points is still sufficient so that the head does not suddenly strike a hard point. The velocity factor is defined as quotient of the adapted and original HIC value at 40 km/h.

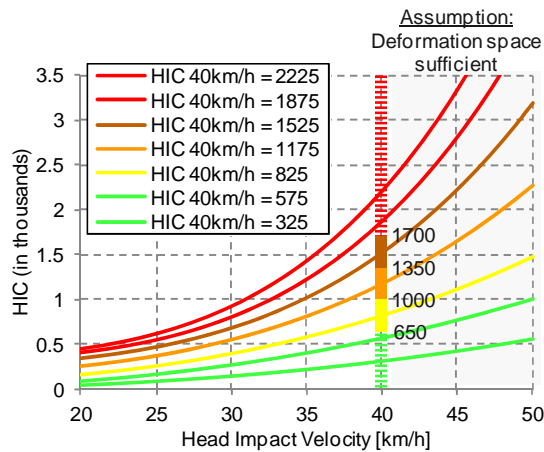


Figure 4. HIC-velocity diagram.

The correlation between head impact velocity and HIC value is related to the stiffness at the test location. The behaviour for a stiff area with high HIC values is more dependent on impact velocity than for a flexible area. Although the presented velocity factor definition is primarily validated for the bonnet, the stiffness based approach behind it in principle allows an application to the windscreen area as well. Hence, and due to the complex and unpredictable behaviour of the windscreen, no separate definition of the velocity factor is used here.

Finally, the angle factor adapts the velocity-related HIC values to the maximal head impact angles of the particular WAD zones ( $W_{i,WAD}$ ) as described in [1].

### Index calculation

The basis for the index calculation forms an injury risk curve. It assigns a probability for an AIS 3+ (Abbreviated Injury Scale) head injury, i.e. a severe to fatal injury (AIS 0 = uninjured, AIS 6 = fatally injured), to each HIC value. The originally used curve specified an AIS 3+ head injury risk of 24% for an HIC value of 1000. However, several studies show higher risk values for a pedestrian accident. In [4] and [5], for example, an AIS 3+ injury risk of 50 to 60% is stated for the head impact of a pedestrian with respect to a HIC value of 1000.

The risk curve used in the following is based on work done by the National Highway Traffic Safety Administration (NHTSA) regarding the head impact in the upper interior according to FMVSS 201 [6]. It is illustrated in Figure 5 and provides an AIS 3+ head injury risk of 53% for an HIC value of 1000. The associated function forms the basis of the index calculation and enables an automated assignment of injury risks to every field of the vehicle zoning.

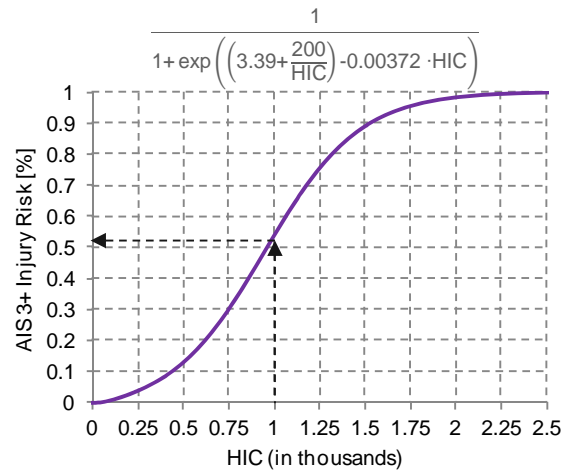


Figure 5. Injury risk curve for an AIS 3+ head injury [6].

The index calculation is based on a totals formula, which sums up the HIC-dependent injury risk of the individual vehicle fields in consideration of their relevance. The head index reaches values between 0 and 1. Two equations have been defined. Equation 1 refers to all vehicles which have been tested by Euro NCAP before 2013 while Equation 2 comprises all necessary changes due to the introduction of the GRID procedure. The definition of the vehicle zoning is represented by the indices  $i$  and  $j$ .

$$\sum_{i=1}^{10} R_{i,WAD} \cdot \left( \sum_{j=1}^{12} \frac{R_{j,lateral}}{1 + \exp \left( \left( 3.39 + \frac{200}{HIC_{ij} \cdot V_{ij} \cdot W_{i,WAD}} \right) - 0.00372 \cdot HIC_{ij} \cdot V_{ij} \cdot W_{i,WAD} \right)} \right) \quad (1)$$

|                 |   |
|-----------------|---|
| i               | Number of WAD zones in longitudinal direction                     |
| $R_{i,WAD}$     | Relevance factor in longitudinal direction, dependent on WAD zone |
| j               | Number of fields in lateral direction                             |
| $HIC_{ij}$      | Euro NCAP HIC value in particular field of vehicle front          |
| $V_{ij}$        | Velocity factor in particular field of vehicle front              |
| $W_{i,WAD}$     | Angle factor in particular WAD zone                               |
| $R_{j,lateral}$ | Relevance factor in lateral direction, constant = 1/12            |

$$\sum_{i=1}^{13} R_{i,WAD} \cdot \left( \sum_{j=1}^{n_i} \frac{R_{ij,lateral}}{1 + \exp \left( \left( 3.39 + \frac{200}{HIC_{ij} \cdot V_{ij} \cdot W_{i,WAD}} \right) - 0.00372 \cdot HIC_{ij} \cdot V_{ij} \cdot W_{i,WAD} \right)} \right) \quad (2)$$

|                  |   |
|------------------|---|
| $n_i$            | Number of grid points in lateral direction  |
| $R_{ij,lateral}$ | Relevance factor in lateral direction, dependent on number of grid points within one WAD zone |

The equations reveal how the data out of the particular modules goes into the index calculation. By means of the relevance factor in longitudinal direction the impact probabilities are assigned to each WAD zone. The velocity and the angle factor are directly integrated into the injury risk function, where they adapt the HIC values of the individual vehicle fields to the simulated accident kinematics.

The whole assessment procedure is processed automatically with the help of MS Excel tools. The input needed for those tools are the corresponding impactor results stated in the Euro NCAP spreadsheet and the simulation data, i.e. head impact velocities, impact angles and impact positions of the different pedestrian models.

The revised index calculation leads to increased head index values. Taking the experimental vehicle presented in [1] as an example, the head index value for children raises from 0.4 to 0.55 while adults show an increase from 0.45 to 0.63.

The modules considered so far allow the assessment of the passive safety of a vehicle front as well as implemented deployable systems depending on the collision speed. In order to use them for the assessment of active safety systems appropriate test results and a methodology to implement those results into the assessment procedure are necessary. This is the task of module 6.

## EVALUATION OF ACTIVE SAFETY

The basis for the assessment forms the reduction in collision speed achieved by an active safety system and the associated changes regarding the head impact probabilities, velocities and angles.

### Velocity-related index calculation

The correlation between collision speed and head index value illustrated in Figure 6 forms the interface between active and passive safety. In addition to the basic value at a collision speed of 40 km/h further supporting points based on corresponding simulations are required. By interpolation between the respective supporting points an index value can be determined for every speed reduction within the regarded range (Figure 6).

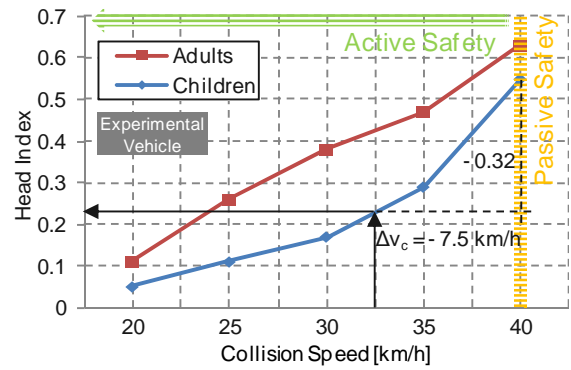


Figure 6. Velocity-related index calculation.

The index values given in Figure 6 are calculated for the basic version of the experimental vehicle, i.e. no additional safety systems are implemented. For children an assumed decrease in velocity of 7.5 km/h leads to an index reduction from 0.55 to 0.23. For adults the decrease of the injury risk is less pronounced.

With the help of the velocity-related index calculation the safety potential of a speed reduction can be directly related to the passive vehicle safety. Thereby a direct link to an external test protocol for active pedestrian safety systems is established.

### External test protocol

Within this paper the implementation of a test protocol developed by the vFSS (Advanced Forward-Looking Safety Systems) initiative is demonstrated but the use of other protocols is possible as well. The vFSS consortium comprises several automobile manufacturers, the German Federal Highway Research Institute (BASt), the expert organisation DEKRA and representatives of the German insurance industry [7].

All four test scenarios of the vFSS protocol (Figure 7) correspond to the general assessment scenario, which describes a pedestrian crossing in front of a vehicle driving with a velocity of 40 km/h (perpendicular moving directions). Thereby, the comparability to the assessment of passive safety measures is guaranteed.

|                      | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 |
|----------------------|------------|------------|------------|------------|
| Sight Obscuration    | yes        |            | no         |            |
| $V_{\text{Vehicle}}$ | 40 km/h    |            | 40 km/h    |            |
| Dummy                | Child      | Adult      | Child      | Adult      |
| $V_{\text{Dummy}}$   | 10 km/h    | 5 km/h     | 10 km/h    | 5 km/h     |
| TTC                  | 1300 ms    |            | 2700 ms    |            |
| Relevance            | ~17%       | ~15%       | ~17%       | ~51%       |

Figure 7. vFSS test scenarios. [8] [9]

The tests are performed under defined boundary conditions and with the help of special test rigs. A distinction is made between scenarios with and without sight obscuration, which lead to a different time to collision (TTC). Furthermore, child and adult dummy targets are used. The child dummy target represents a 6 year old child running from the left while the adult dummy target simulates a walking 50th percentile male coming from the right. [9]

For the testing of systems with warning and/or driver-triggered braking a robot is used which simulates a low-performance driver with a slow reaction time and an overly cautious braking. [7] To avoid that a system is only designed for the test parameters additional tests outside the defined test conditions, so called pin pricks tests, are intended.

### Generic AEB system

The defined case example describes an AEB system equipped with a warning function. Does the driver not react to the warning or is a warning not possible any more, the system performs an automatic emergency brake with maximum deceleration 0.6 seconds prior to the collision. Furthermore, the generic system detects, despite the higher velocity of the child dummy target defined in the test protocol, children and adults equally. Thus, the speed reductions in the particular test scenarios are the same for both pedestrian groups since the other boundary conditions (TTC, vehicle speed) are consistent.

In the scenarios with obstructed pedestrian (TTC = 2700 ms) the braking robot reacts to the system warning and triggers the brake assist system. Although a low-performance driver is simulated a

collision can be avoided by the initiated optimal deceleration. Accordingly, the resulting injury risk for scenario 3 and 4 is 0%.

### Assessment methodology

The assessment methodology, which converts the speed reductions achieved within the particular scenarios into an active safety index, is illustrated in Figure 8 for children and in Figure 9 for adults.

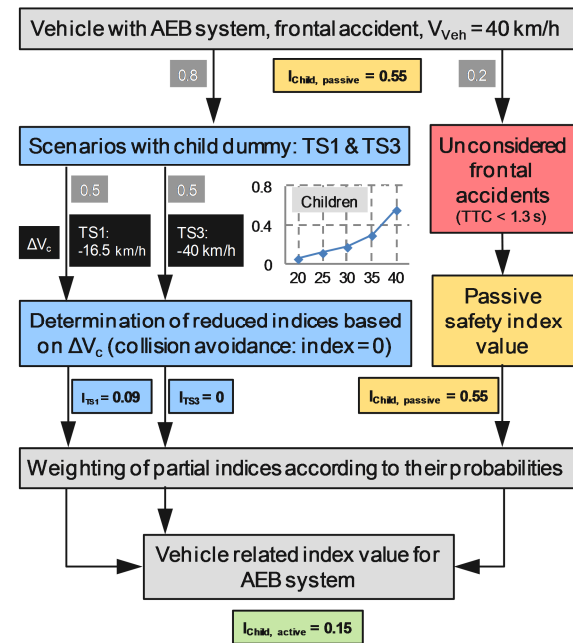


Figure 8. Assessment methodology for children (generic test results, experimental vehicle).

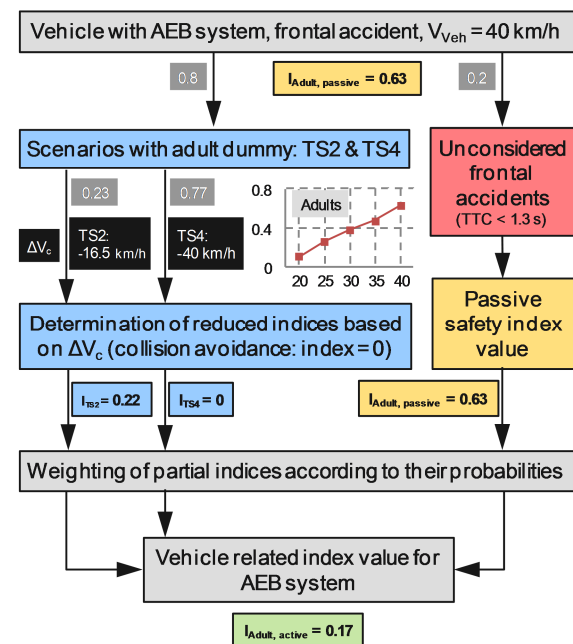


Figure 9. Assessment methodology for adults (generic test results, experimental vehicle).

For the test scenarios with unobstructed pedestrian (TS1 & TS2) a timely driver warning is not possible due to the short TTC of 1300 ms. The speed reduction arising from the automatic emergency braking at  $TTC = 0.6$  s is 16.5 km/h, assuming a build-up time until maximum deceleration of 0.4 s [10].

Starting with the passive safety index at 40 km/h, partial indices are determined for the particular branches of the scheme and added up under consideration of their relevance (highlighted in dark grey). The percentage of frontal accidents which are not covered by the test scenarios is considered by a separate branch. Decisive is the lowest TTC defined within the test protocol. In the case of the vFSS protocol the lowest TTC is 1300 ms. Due to the GIDAS database the proportion of frontal pedestrian accidents with a TTC below 1300 ms is about 20% [8]. Since the specified test scenarios do not prove an additional safety potential here, the passive safety index is used. This approach takes into account that an active safety system, in contrast to passive safety measures, cannot be effective in all frontal accidents. The general technical robustness of the system has to be verified prior to the assessment by appropriate “pin pricks tests”.

With respect to the frontal accidents covered by the test protocol the probabilities of the different branches arise from the relevancies of the underlying scenarios (Figure 7). While for the children the relevancies of the corresponding scenarios are equal, the adults show a significantly higher relevance regarding the unobstructed scenario. The values given in Figure 8 and 9 are scaled to 100%. With the help of the correlation between collision speed and head index determined for the example vehicle (Figure 6) the speed reductions achieved in the particular scenarios can be transferred into corresponding index values. If the accident can be prevented, the index is set to zero. Below a collision speed of 20 km/h no further supporting points are provided. Here the index values are calculated by linear interpolation between zero and the index result for 20 km/h. Instead of using supporting points, it would also be possible to directly consider the actual test results, i.e. the achieved collision speeds, in the kinematics simulations and index calculation respectively.

For the regarded example vehicle the equipment of the generic AEB system leads to a significant reduction of the head indices. For children a result of 0.15 is achieved while the adults reach a slightly higher value of 0.17. The reason for this is the poorer passive safety index calculated for adults. Thereby the partial indices, especially the important one defined for the unconsidered frontal accidents,

are accordingly higher. In principle, however, lower values can be expected for adults compared to children due to the higher relevance of the unobstructed scenario which generally allows higher speed reductions up to a total avoidance of the collision.

## HEAD INDEX RESULTS

In the following index values are calculated for six real passenger car fronts (Figure 10), all representing different vehicle classes (Compact Car, Sedan, Van, Sports Car, SUV, OneBox). Those classes are based upon a categorisation, which has been developed to consider the different front designs of modern cars and their impact on pedestrian accident kinematics.

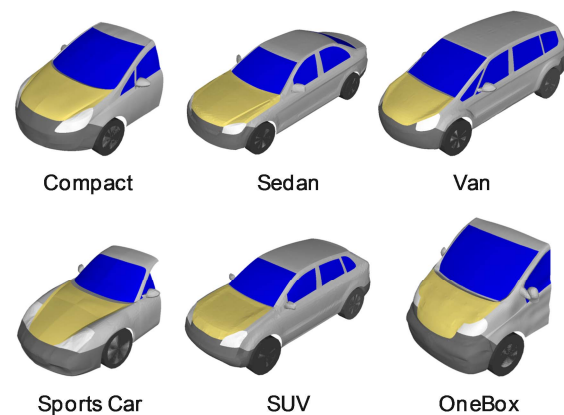


Figure 10. Simulation models of vehicle class representatives.

Three geometrical parameters are used for classification. The first one is the height of the bonnet leading edge (BLE), which has significant influence on the accident kinematics of a pedestrian. The WAD up to the bonnet rear edge is relevant for the location of the primary head impact relative to the vehicle front. The lower the value for this parameter, the higher is the probability for a head impact in the windscreen area. The third characteristic parameter is the bonnet angle, which has an effect on the pedestrian WADs. [1]

Besides the pedestrian accident kinematics data, the structural properties of the vehicle front have a decisive effect on the head index result as well. Figure 11 illustrates the Euro NCAP test results of the different vehicle class representatives. The sports car is the only vehicle where generic test results in form of a classical A-pattern have been assigned according to the vehicle zoning (Figure 2). A representative out of this class has so far not been tested by Euro NCAP. The poor results of the sedan are not representative for the vehicle class but demonstrate the head index spectrum. The calculation of the leg index is described in [1].

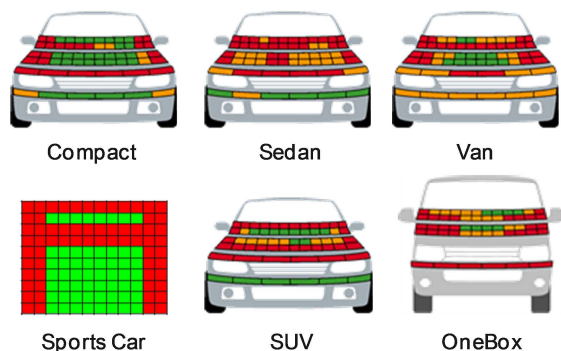


Figure 11. Structural properties of basic vehicles (Euro NCAP, Sports Car with generic results). [11]

In addition to the basic vehicle, an active bonnet, a windscreen airbag and the generic AEB system are each assessed. For the area protected by the inflated airbag HIC values of 500 are defined. In case of the active bonnet a value of 600 is assigned to the particular fields while the lateral and rear boundary areas keep their values. The corresponding children head indices are illustrated in Figure 12, whereas the adult indices are shown in Figure 13. The index values reveal, which pedestrian safety systems are most effective for the different vehicle classes as well as pedestrian groups.

### Head index results of the children

For children the AEB system offers the highest safety potential across all vehicle classes. The implementation of an active bonnet is reasonable as well since it usually covers the most relevant impact areas for children, so that a high percentage profits from the reduced HIC values arising from the bonnet lifting. In case of the compact car the additional benefit of the active bonnet is limited due to the good test results in the bonnet area of the basic vehicle. Moreover, the lower HIC values achieved by the active bonnet are partially compensated by increased head impact velocities, which result from the steeper bonnet angle.

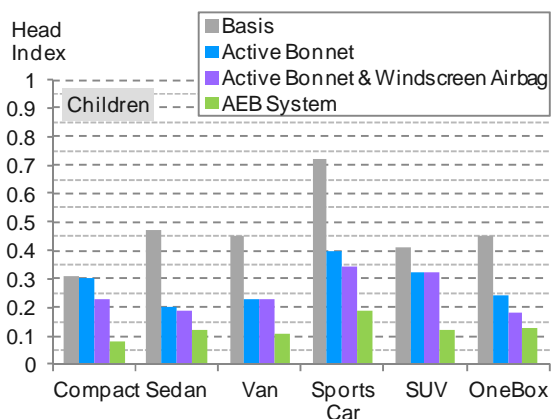


Figure 12. Head index results of the children.

Noticeable are the comparatively high index values of the sports car. As mentioned above, the sports car is the only vehicle where generic test results have been assigned. However, the reason for the increased index values is not the definition of the structural properties but the occurring head impact velocities, which mainly lie above the collision speed. The low BLE height combined with a flat bonnet angle lead to a high rotational velocity of the pedestrian models and thus to high head impact velocities.

As expected, a windscreen airbag offers little or no additional protection for children. The covered area is in most cases not relevant with respect to small pedestrian heights.

### Head index results of the adults

Apart from the SUV, the indices calculated for the adults (Figure 13) turn out higher than the children values. This is due to the different impact areas of both pedestrian groups. Whereas the children predominantly impact in the bonnet area, the adults often strike the cowl, the A-pillars or the lower windscreen area, which are largely critical with regard to the structural properties.

A windscreen airbag forms, in combination with an active bonnet, a highly effective safety measure for adults since it covers the most critical and at the same time the most relevant impact areas. The high relevance of the windscreen airbag also results from the forward displacement of the head impact locations caused by the deployed bonnet. Thereby the relevance of the cowl area increases significantly. According to this the benefit of a separately applied active bonnet, i.e. without airbag, is limited and can even have a negative effect on the index value. Moreover, there is an additional injury risk due to the gap at the bonnet rear edge. This is considered by the specification of a minimum HIC value of 1500 for those fields of the active bonnet.

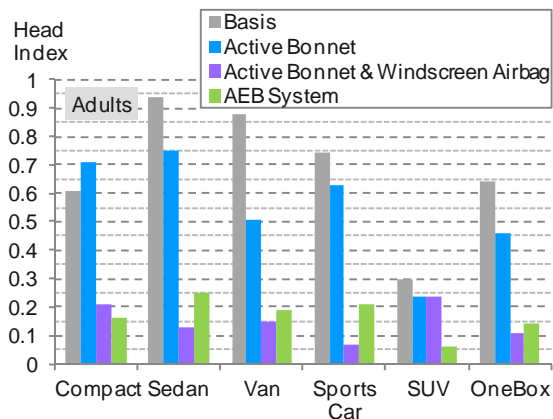


Figure 13. Head index results of the adults.

The AEB system is very effective as well, even if it does not reach the low risk level of the windscreen airbag for the majority of classes. The reasons for this are the above mentioned good coverage of the relevant head impact areas by the airbag but first of all the insufficient passive safety the basic vehicles offer here. Decisive in this regard is the corresponding high partial index value for the unconsidered frontal accidents. This ensures that passive safety cannot be neglected in case that an active safety system is applied.

Conspicuous are the comparatively low head indices of the SUV. Here, the calculated values reflect to some extent the positive Euro NCAP test results for this vehicle class. The large bonnet dimensions, i.e. long WAD up to the bonnet rear edge and according relevancies for adults, in combination with the possibility to establish sufficient deformation space generally provide favourable boundary conditions with regard to the head impact. Furthermore, the head impact velocities are comparable to a sedan car, for children they are even slightly lower. However, the injury risk due to the high BLE is neither reflected by the head nor by the leg index. The same applies to the related Euro NCAP component tests.

The results in [12] show that, on average, head injuries are similar or slightly lower from contact with SUVs compared to cars, but injuries to the mid-body regions are substantially higher. Here, there is an increased risk due to the high BLE. The mid-body region is directly struck in the primary impact, leading to less rotation of the body. This increases the impact efficiency and the overall momentum transfer from the vehicle to the pedestrian is greater, whereas the additional mass of SUVs is not very significant for pedestrian injury causation. [12] Unfortunately, the mid body region is not or only insufficiently considered by the Euro NCAP tests and therefore hardly to be implemented into the assessment procedure.

The problem of rating high fronted vehicles by the current component tests becomes apparent using the example of the Ford Ranger. The Ford Ranger is a Pick-up with a BLE height above 1000 mm. It falls into the class SUV since only the front geometry is decisive for the classification. The Ford Ranger achieves a Euro NCAP pedestrian protection rating of 81% without having any additional safety systems, i.e. solely by structural improvements at the vehicle front. At the moment a score of 60% would be sufficient to receive a five star rating. Interesting in this regard is a comparison with the results of the Volvo V40, which is equipped with the latest advanced pedestrian safety systems. These include an active bonnet as well as the first series windscreen airbag.

The resultant score is 88%, the best result for pedestrian protection reached so far but at the same time still in the range of the Ford Ranger.

The OneBox vehicle possesses a high BLE as well. However, due to its steep bonnet angle, the significantly shorter WAD up to the bonnet rear edge and the poor test results the head index values turn out higher.

## CONCLUSIONS

The presented procedure enables an integrated assessment of active and passive pedestrian safety measures on one scale for both children and adults. An important characteristic of the assessment procedure is its modular design, combining structural characteristics of a vehicle front with accident kinematics and accident research data. Each module can be enhanced or changed independently. In principle, the vehicle-model-specific Euro NCAP results are adapted to the real accident kinematics derived from numerical simulations and weighted according to the impact probability of the related wrap-around-distance zones of the vehicle front. Those impact probabilities are based on representative size distributions for children and adults, which are derived from the GIDAS database. Further kinematics parameters are the maximum head impact velocity as well as impact angle within each WAD zone. The assessment procedure finally provides an index value, which indicates the risk for an AIS3+ head injury due to the primary impact depending on the collision speed. The whole process is automated to a large extend.

The main criterion for the evaluation of active pedestrian safety systems is the reduction in collision speed achieved within the particular scenarios of an external test protocol. A methodology has been developed, which implements those test results according to their relevance into the assessment procedure and enables the calculation of corresponding index values for children and adults. In order to achieve minimal active safety indices good results in the Euro NCAP component tests are required. This ensures that passive safety cannot be neglected in case that an active safety system is applied. Furthermore, the methodology rewards the definition of challenging active test scenarios.

Several updates have been made to the assessment procedure. Due to the implementation of the Euro NCAP-GRID the future applicability of the procedure is guaranteed. Besides the use of GIDAS based size distributions the index calculation itself has been revised. This includes the integration of a more convenient injury risk curve as well as the

definition of a new HIC-velocity diagram with an improved family of curves.

The assessment procedure has been applied to different measures and vehicle fronts. The safety potential of passive measures is dependent on the front geometry as well as the pedestrian height. There is no “one fits all” passive measure which performs on the same positive level at all vehicle fronts and for all pedestrian sizes. Therefore they have to be selected and adjusted for each car front. With regard to children the implementation of an active bonnet is beneficial in most cases. However, its safety potential is limited as it actually only generates additional deformation space in order to avoid a head impact on hard points in the engine compartment. The adults profit strongly from a windscreen airbag. The only exception is the SUV where the relevance of a windscreen airbag is low due to the long WAD up to the bonnet rear edge.

An AEB system offers a high safety potential for all regarded vehicle classes as well as pedestrian groups. In case of the children it is the most effective safety measure, regardless of the front geometry. In terms of the adults the influence of the passive safety level on the assessment of active safety systems becomes apparent. The insufficient passive safety of the relevant impact zones results in index values, which often lie above those of the windscreen airbag. Here, an integrated approach would be highly efficient, i.e. the combination of a windscreen airbag with an AEB system. Taking the sedan as an example, such an integrated safety system would reach an index value of 0.03. Since the windscreen airbag also implies the application of an active bonnet, children benefit as well. The corresponding index value amounts to 0.05.

With respect to the safety potential of an active safety system it has to be regarded that a reduction in collision speed is beneficial for all body regions. It is not limited to one body part as this is often the case for passive safety measures. Furthermore, not only the primary but also the secondary impact on the ground can be mitigated or even avoided [13]. Consequently, pedestrian safety measures should follow an integrated safety approach. Only in this way a minimisation of the injury risk is achievable.

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